September 1920. Botanical Series Vol XI, No 1.

Memoirs of the Department of Agriculture in India

SOME ASPECTS OF THE INDIGO INDUSTRY IN BIHAR

PART I

THE WILT DISEASE OF INDIGO IN BIHAR

PART II

THE FACTORS UNDERLYING THE SEED PRODUCTION AND GROWTH OF JAVA INDIGO

BY

ALBERT HOWARD, C.I.E., M.A

Imperial Economic Botanist

AND

GABRIELLE L. C. HOWARD, M.A

Second Imperial Economic Botanist

(With the assistance of Chowdhary Ram Dhan Singh and Maulvi Abdur Rahman Khan, Assistants to the Imperial Economic Botanist.)

AGRICULTURAL RESEARCH INSTITUTE, PUSA

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[Received for publication on 23rd November, 1919.]

When the Indigo Research Station at Sirsiah was closed on March 31st, 1913, investigations on the agricultural and botanical aspects of this industry were transferred to the Botanical Section of the Agricultural Research Institute at Pusa. About this time, the cultivation of Java indigo in Bihar had reached its lowest point, having fallen from 70,000 to about 15,000 *bighas* between 1910 and 1914, largely on account of the wilt disease and the difficulty of obtaining seed. These and other aspects of the industry have been under investigation during the last six years. An account of the earlier results appeared in Bulletins 51, 54 and 67 of the Agricultural Research Institute, Pusa. The present paper deals with the causes of indigo wilt and with its prevention.

Java indigo (*Indigofera arrecta* Hochst.) is a perennial tropical crop which was first introduced into Bihar from Java in 1898. The climate of Bihar is

tropical, as far as temperature is concerned, from March to November, but December, January, and February are too cold for the growth of this crop. When first introduced, Java indigo did exceedingly well, yielding heavy crops of leaf, rich in *indican*, as well as abundant seed. After some years, however, the plant began to show increasing signs of want of vigour and finally began to die of wilt during the second half of the rainy season. At the same time, the yield of seed diminished. The degeneration was progressive and by 1913, when we took up this investigation, many planters had already abandoned the cultivation while others had considerably restricted the area under this species.

Wilt usually makes its appearance after the first cut during July and August, the severity of the attack depending on the season. Affected plants stand out clearly from normally grown individuals and are easily recognized in the field. At first, there is a slowing down of growth while the foliage alters in appearance, the leaves become folded longitudinally and assume a yellowish-green, slaty colour. Leaf-fall is then rapid until only a tuft of stunted foliage is left at the tips of the branches. Afterwards, the plants die off in stages, the process taking place slowly, a branch at a time.

A good deal of attention has been devoted by previous investigators to the cause of indigo wilt. Neither insects, fungi nor bacteria have been shown to be responsible for the trouble. Our investigations indicate that wilt results from the destruction of the fine roots and nodules under circumstances when regeneration is difficult or impossible. In the following pages, the evidence is recorded on which this conclusion is based. Before dealing with the actual observations and experiments, a brief reference to the chief factors underlying the cultivation of Java indigo in Bihar is necessary to bring out the significance of much of the following.

I. The Factors.

Soil. The soil of the Bihar indigo districts is a silt (often containing large quantities of finely divided calcium carbonate) belonging to the older alluvium of the Gangetic plain. Its main characteristics, from the point of view of the indigo plant, are its depth, the uniformity of its fine particles, its water holding capacity during the hot months of April, May, and June, the comparative nearness to the surface of the sub-soil water and the low content of oxygen in the deeper layers, as shown by the analyses of well-waters. The sub-soils often show rust coloured markings associated with green and blue

tints which, according to Hilgard,[1] indicate a lack of aeration in consequence of imperfect drainage. The indigo soils easily run together on the surface after moderate rain forming a well-defined crust, known to the cultivator as the *papri*. After long continued heavy rain, this crust may become several inches thick, the porosity of which is not recovered until the land dries and is cultivated. An excessive rainfall besides producing these impermeable crusts, also leads to the waterlogging of the pore spaces of the upper soil (probably due to deflocculation of the clay particles) for comparatively long periods.[2]

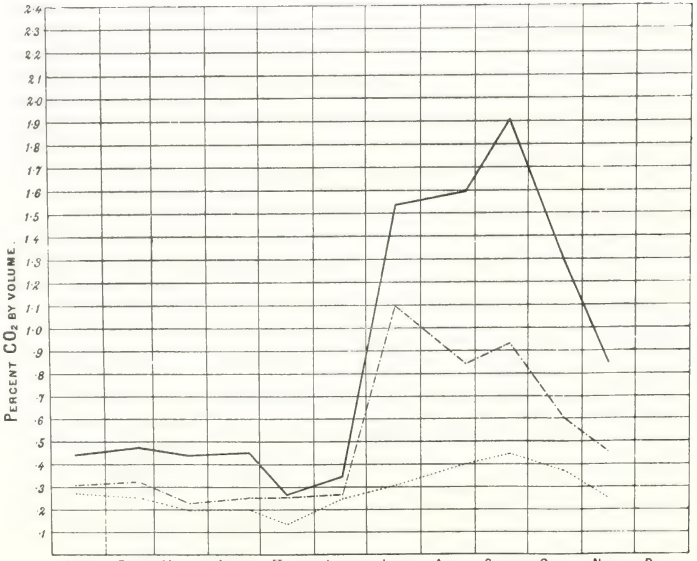
Rainfall. The average annual rainfall is in the neighbourhood of 50 inches, most of which falls during the period May to September (Table 1).

[1] Hilgard, "Soils," 1906, p. 45.
[2] *Agr. Jour. of India*, Special Indian Science Congress Number, 1919, p. 381.

TABLE I.

Rainfall at Pusa during the years 1906–1919.

Month	1906	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	1917	1918	1919	Average
January ..	..	0·00	0·47	0·11	0·01	0·27	0·13	0·00	0·00	0·13	0·00	0·13	0·00	1·29	0·18
February ..	2·20	1·22	2·27	0·00	0·02	0·00	0·11	1·44	0·97	1·73	0·44	0·75	0·00	0·02	0·80
March	0·21	1·77	0·10	0·23	0·07	0·57	0·80	0·43	0·11	1·31	0·00	0·32	0·09	0·02	0·43
April	0·00	0·89	0·00	3·47	0·14	0·14	1·18	0·01	1·94	0·26	0·31	0·00	0·69	1·36	0·76
May	1·93	0·33	0·92	1·34	0·41	0·33	3·14	7·00	1·86	1·99	0·37	3·48	3·69	0·68	1·96
June	5·48	6·88	1·48	28·96	7·46	11·79	1·61	17·71	4·21	5·07	9·67	7·96	11·50	2·21	8·93
July	11·99	7·68	7·21	10·08	9·31	9·21	14·18	10·22	10·19	16·25	10·62	12·51	11·64	14·78	11·16
August	24·81	6·14	3·85	24·11	6·88	17·98	9·63	18·57	28·83	21·97	15·85	5·35	26·68	5·54	15·44
September . ..	3·06	14·80	4·97	4·51	3·70	8·09	3·33	8·17	6·13	4·67	13·90	10·77	6·43	5·11	6·97
October	0·57	0·00	0·58	2·40	4·16	3·13	0·16	1·07	0·09	0·93	4·95	1·88	0·00	1·89	1·59
November . ..	0·00	0·00	0·00	0·00	0·14	0·71	4·03	0·00	0·00	0·56	0·00	0·00	0·00	..	0·39
December	0·00	0·00	0·01	0·12	0·00	0·00	0·00	1·13	0·03	0·02	0·00	0·01	0·00	..	0·10
TOTAL	50·34	39·71	21·92	75·83	32·33	52·52	41·00	65·75	54·36	54·89	56·11	43·16	60·72	32·90	48·71



CARBON DIOXIDE IN THE SOIL ATMOSPHERE AT PUSA.

PLATE I.

July and August are the wettest months. From November to April very little rain is received. The humidity is generally high and is lowest in March and April when it falls to about 60.

Temperature. There is a well-marked cold season, December to February, when the minimum temperature remains in the neighbourhood of 50°F. In the hot weather months, March, April and May, the dry west winds are important agents in improving the aeration of the soil. The monsoon period June to September is hot and damp. After the middle of October, the temperature gradually falls till cold weather conditions set in at the end of November.

Soil aeration. Periodical determinations of the amount of carbon dioxide in the soil atmosphere have been carried out in the Botanical area at Pusa by Mr. Jatindra Nath Mukherjee under the direction of Dr. Harrison, Imperial Agricultural Chemist, on cultivated and grass land for a period of eleven months. The results are given in Table II and in Plate I. A note by Mr. Mukherjee on the methods adopted is appended to this paper.

TABLE II.

Percentage of CO_2 in the soil gas from three different plots in the Botanical Area, Pusa, in 1919.

Date and month when the soil gas was aspirated and analysed	Plot No. 1 Grassed down	Plot No. 2 Grassed down but partially aerated by trenches	Plot No. 3 Surface cultivated	Rainfall in inches since 1st January, 1919
13th, 14th and 17th January ..	0·444	0·312	0·269	*Nil.*
20th and 21st February ..	0·472	0·320	0·253	1·30″
21st and 22nd March ..	0·427	0·223	0·197	1·33″
23rd and 24th April ..	0·454	0·262	0·203	2·69″
16th and 17th May ..	0·271	0·257	0·133	3·26″
17th and 18th June ..	0·341	0·274	0·249	4·53″
17th and 18th July ..	1·540	1·090	0·304	14·61″
25th and 26th August ..	1·590	0·836	0·401	23·29″
19th and 20th September ..	1·908	0·931	0·450	30·67″
21st and 22nd October ..	1·297	0·602	0·365	32·90″
14th and 15th November ..	0·853	0·456	0·261	32·90″

These figures and the curves (Plate I), give a general idea of the soil atmosphere as regards ventilation in a year exceedingly favourable to the indigo crop. Aeration is at its best during the period of the west winds—March to May. After the monsoon has set in, the proportion of carbon dioxide

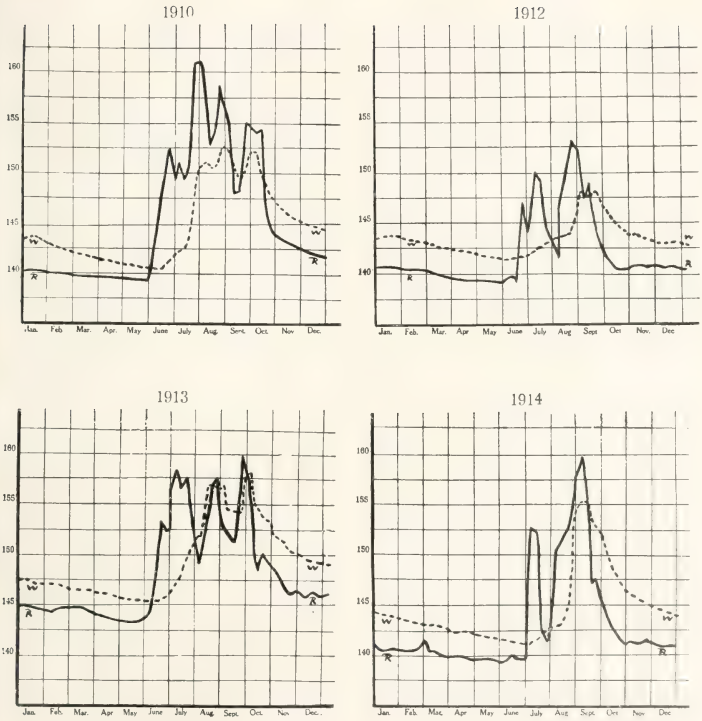
rises and remains at a fairly high level till October when it rapidly falls.[1] Of perhaps greater significance in this respect are the movements of the ground water. In the indigo areas of Bihar, the flow of the rivers is often checked during the monsoon by the rise of the level of the Ganges. As a result, the rivers overflow and the lowlying areas go under water. The rise in the level of the rivers is followed by a rise in the water-level of the wells. These movements of the river level and of the general ground water are illustrated in the curves opposite (Plate II) which represent the state of affairs of the river at Pusa and of one of the wells (about a quarter of a mile distant from the river bank) for the years, 1910, 1912, 1913 and 1914. This upward movement of the ground water, which must push in front of it the soil air from the deeper layers, occurs at a period when the general drainage of the country is checked and when the permeability of the surface soil is poor due to consolidation by heavy rain. We should expect, therefore, that the aeration of the soil will be at its lowest point during the second half of the rainy season.

Briefly stated these are the conditions under which a tropical leguminous plant has to grow in Bihar. The range is wide. The crop is sown at the end of the rains in late September or early October, when the surface soil is sufficiently warm and moist for rapid germination. By the beginning of the cold weather in December, the plant is three or four inches high. Growth then ceases till March. After the rains set in towards the end of May or early in June, growth is exceedingly rapid and the first cut is taken at the end of June or early in July. The stumps shoot again and the second crop is harvested in late July or early August, followed, in good years, either by a final cut in September or by a crop of seed during the cold weather. After this, the stumps are dug out and the land is prepared for other crops. The original practice in Bihar was to raise the seed after at least two crops of leaf and at a period in the life-history of the plant when its vigour was at its lowest point.

II. The Cause of Wilt.

The earlier results relating to the cause of wilt of Java indigo were published in 1916, in *Pusa Bulletin* 67. Since that time, the subject has been investigated afresh but in much greater detail with the consequence that our former conclusions have been confirmed in all respects. Briefly stated, we have found that when the roots and nodules of an indigo plant have suffered extensive damage, wilt invariably results from any cause which interferes with

[1] It is possible that other deleterious substances beside carbon dioxide are produced in Bihar subsoils during the rainy season. The subject needs further investigation.



CHANGES IN THE RIVER AND WELL LEVELS AT PUSA.

The well levels shown by dotted lines. The observations are expressed in feet above mean sea level.

normal root regeneration. Several factors have been discovered which prevent the repair of the root system. In indigo cultivation, the chief source of damage to the active roots and nodules arises from the complete cutting back of the plant.[1] This results in the destruction of practically all the fine roots and nodules and root regeneration is necessary before new growth can take place. If the absorbing root system is destroyed when the soil aeration is poor, when the amount of reserve material in the tap root is insufficient for new roots to be formed, or when the soil temperature is too low for growth, root regeneration becomes exceedingly difficult and wilt follows. Thus although the cause of wilt is the same in all cases, the agents which produce it may be different. In considering the incidence of wilt in Bihar, it is necessary, therefore, to understand fully in every case the factors which are concerned in root regeneration. If this is done, all the known cases of wilt fall together and are capable of a simple explanation.

As the nodules and active root system appeared to be of particular importance in this question, a great deal of attention has been paid thereto. The condition of the roots and nodules, however, cannot be determined with precision by observation of the above ground portion of the crop. It was necessary to find some easy method of rapidly exposing without damage the complete root system including the finer branches and the nodules. This was accomplished by the use of an ordinary knapsack sprayer. The results obtained by following the root development throughout the year have proved of the very greatest value in the elucidation of this interesting problem.

Root development in Java indigo.

The development of the root system of the ordinary indigo crop, sown in late September or early October, has been examined for several seasons by means of periodical root washings. At first, the tap root extends rapidly in length and by the beginning of the cold weather practically no large laterals are developed. The root system at this stage consists of a long tap root with comparatively fine laterals and a certain amount of nodular development. During the cold weather, the extent of the active absorbing system is small and little or no growth of roots takes place. With the renewal of activity at the beginning of the hot weather in March, new absorbing roots are copiously developed and the laterals increase in thickness. Nodular development begins

[1] A large number of root washings have been made, at all stages of growth, after indigo plants have been cut back to varying extents. Complete cutting back always kills the fine roots and most of the nodules. Heavy pruning results in extensive root and nodular destruction but not to the same extent as when the plants are completely cut back.

in April, but does not become intense till the soil is cooled and moistened by the early monsoon rains in May when the numbers formed are very large. As would be expected, these bodies are much more abundant in the first four inches of soil than in the deeper layers. No further changes occur till the first cut is taken. Cutting back is followed by the destruction of practically all the fine roots and of most of the nodules. Before new growth can take place, root regeneration is necessary. The extent and speed of this regeneration is found to depend on the aeration of the soil. If the rainfall is low and if the levels of the rivers and wells do not rise to any great extent, as in 1919, the fine roots and nodules are rapidly renewed. Thus in the case of the root systems of three plants exposed on June 14th, 1919, 194 nodules were found on the upper laterals. These were removed and the soil quickly replaced. A month later, the roots of these plants were again exposed and numerous new fine roots and no less than 942 fresh nodules were found. The reaction of the roots to alterations in the soil atmosphere during the rains is very striking. After the middle of July and at the beginning of September of the present year, 1919, when heavy rains, combined with the rise of the ground water, adversely affected the aeration of the soil, an immediate root response to the changed soil conditions took place. The fine roots in the deeper layers of soil were quickly killed, new roots were only formed near the surface of the ground while the finer branches of the upper laterals were found to exhibit marked aerotropism and to bend upwards towards the air. This continued on both occasions till a break in the rains and a fall of the ground water restored soil aeration when normal root development again ensued. During the late rains, the formation of fine roots and nodules is almost always restricted to the upper four inches of soil. At this time, the lower regions of the tap-root and the lower laterals are practically devoid of nodules and small roots and the current of crude sap is maintained entirely by the fine roots near the surface of the ground. This is effective while monsoon conditions prevail but when the rains cease and the upper layers of the soil dry, the plants either become wilted or else shed their leaves and pass into a resting condition during the cold weather.[1] Root and shoot growth are resumed when the soil temperature rises in March.

In the case of Java indigo sown for seed in August, the feature of the root system is the development of abundant nodules on the upper roots during late September and October. These, however, become absorbed during

[1] Mulching the soil to prevent the loss of moisture acts as a preventative of wilt during October, November and December.

November and December after flowering sets in. During the cold weather, the roots of seed plants show few active rootlets and extensive regeneration does not take place till the temperature of the soil rises in March.

In both the ordinary and the seed crop, therefore, the features of the root system may be summed up as follows :—

(1) The periods of intense nodular development are at the break of and during the early rains and, in the case of the seed crop, in September and October.

(2) Temperature, soil aeration and moisture are the chief factors in the formation of absorbing roots and nodules.

(3) Although the nodules and fine roots are easily destroyed, the main tap-root and the larger laterals possess remarkable vitality and are capable of remaining dormant in the soil without damage from December to March, after which they often produce a new set of absorbing roots and nodules.

Observations and experiments on the cause of wilt.

The evidence on which we have based our conclusions as to the cause of wilt has been obtained by several methods. The root systems of numerous healthy and wilted plants have been compared in detail, the occurrence of wilt in Bihar has been studied under various conditions extending over many years, actual cases of wilt have been produced artificially in no less than five different ways while many examples of recovery have been closely examined. The conclusions arrived at, as a result of these experiments and observations, have been confirmed by a study of the behaviour of other crops during the rains at Pusa and also by the growth of indigo, on soils differing widely as regards aeration, in other parts of India.

The root systems of wilted and healthy plants. The roots of a very large number of wilted plants have been exposed by the spraying machine and compared with those of healthy plants. The results have always been the same. Where the wilted condition is well marked, healthy nodules are never found while the number of active roots is exceedingly small. Dead and discoloured fine roots and nodules are, however, abundant. In the case of the roots of healthy plants examined at the same time for comparison, there have always been abundant fine roots and root nodules in an actively growing condition. Indigo wilt is, therefore, associated with the recent destruction of the absorbing root system.

In the rains, wilt occurs on deep-rooting types to a much greater extent than on those with a shallow root system. Java indigo, as grown in Bihar, is an exceedingly mixed crop and consists of a large number of

types which, however, fall into two main classes as regards branching and root development :—

(1) Bushy types which branch to very varying degrees from the base, the branches coming off nearly at right angles to the main axis. There is a general correspondence between the method of branching of the stem and of the root. The root system is the mirror image of the shoot. In those bush types which branch at right angles to the axis, the lateral roots are also given off at right angles to the main tap-root.

(2) Tall vertical types whose branches arise at an acute angle from the stem. In the vertical types, the lateral roots arise at an angle very similar to that in the case of the branches.

These general differences are shown in Figs. 1 and 2 and in Plate III. Running through both these classes of branching are great divergencies in the time of flowering and in the rate of growth. Some are early, others are exceedingly late. Some grow slowly, others much more rapidly. All grades of intermediates naturally occur. Five main types of root-development have up to the present been found :—

(*a*) Early bush types in which nearly all the laterals arise at right angles and are concentrated near the surface. Our selected indigo, known as Type 15, belongs to this group. The root system is shown in Fig. 1.

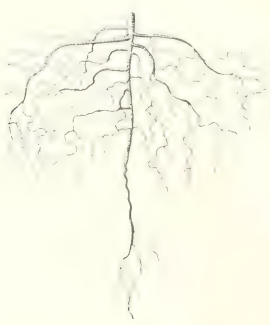


Fig. 1. The root-range of an early bush type of Java indigo.

THE ROOT-RANGE IN EARLY-FLOWERING TYPES OF JAVA INDIGO.

PLATE III.

(*b*) Early types with a vertical habit in which nearly all the laterals are concentrated near the surface but all point downwards. The selection known as Type 11, the roots of which are shown in Fig. 2, belongs to this type.

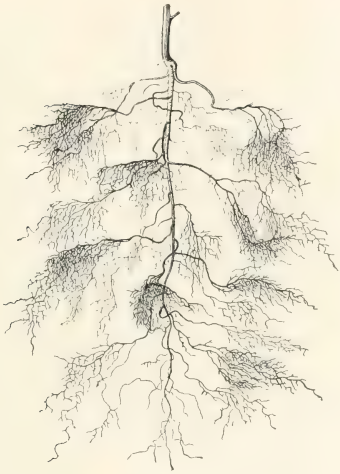


FIG. 2. The root-range of a plant of Java indigo of vertical habit.

(*c*) Late bushy forms in which there is a development of lateral roots from the surface to a great distance down the main root.

(*d*) Late types of vertical habit with lateral roots pointing downwards arising at regular intervals down the long main root.

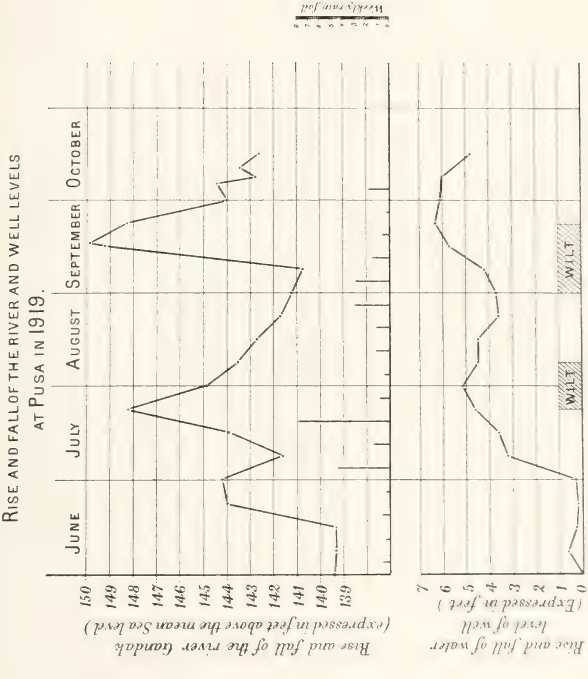
(*e*) Types with hardly any side branches but a deep tap-root. These types scarcely branch at all either above or below ground.

It will be obvious that if poor soil aeration is a factor of importance in the production of wilt, the types which will be affected most are deep-rooting types like (*b*), (*c*), (*d*) and (*e*) while (*a*) will be least affected. In 1917, a comparison was made between the growth and wilt resistance of Type 11, an early type with a vertical habit whose laterals point downwards (Fig. 2) and Type 15, an early bush type with laterals near the surface (Fig. 1). The former proved to be much more wilt liable than the latter. In 1918, this point received further confirmation. It was found that after the first cut, all the plants which did not shoot and which were attacked by wilt could not be uprooted by hand as the laterals ran deep into the soil. On the other hand, the plants which formed healthy new growth could be pulled up with comparative ease as the laterals were much nearer the surface. In 1919, every case of wilt examined in detail during the monsoon was found to be associated with deep-rooting while the healthy plants examined for comparison were all found to be surface-rooted.

The occurrence of wilt under monsoon conditions. The amount of wilt during the rainy season and the general vigour of the indigo crop under estate conditions, have been found to depend on two factors—the rainfall and the rise of the ground water. If the rainfall is heavy, particularly during July and August, and if the ground water rises rapidly and remains at a high level during this period, the second crop is a failure and wilt is widespread. Although unfavourable years are common, they are not universal. In 1919, the monsoon rainfall was about 12 inches below the average, there were no floods and the rise of the ground water was not considerable. The details relating to the rainfall and to the movements of the river and well levels at Pusa, in 1919, are given in Plate IV. Wilt was negligible and only made its appearance on two occasions—between July 23rd and August 7th—and again during the first three weeks of September. Both these attacks were associated with an increased rainfall and a rise in the well levels. They were, however, not severe and had little influence on the yield. Three good cuts of indigo were obtained at Pusa and for many years the indigo crop has never been so healthy after the rains.

Although wilt is often universal during the late rains, it is not uncommon in Bihar to find young self-sown indigo plants in September and October, growing vigorously in fields practically destroyed by disease. In 1912, at Pusa, this occurred on the large scale in a wilted field in which the blank spaces in the lines had been filled by resowing during the first week in August. The late sown plants without exception were not affected by wilt but grew well and gave heavy crops of well-ripened seed. Here, healthy and wilted

PLATE IV.



RISE AND FALL OF THE RIVER AND WELL LEVELS AT PUSA IN 1919.
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
WILT
WILT
Weekly rain fall
150
149
148
147
146
145
144
143
142
141
140
139
Rise and fall of the river Gandak (expressed in feet above the mean Sea level)
7
6
5
4
3
2
1
0
Rise and fall of water level of well (Expressed in feet)

plants grew next to next with interlocking root systems and in no single instance did wilt spread to the late sown plants. Since 1912, many similar examples have been noted which prove conclusively that wilt is neither a disease in the ordinary sense, nor is it caused by any deficiency in the soil solution.

Not only may wilted and healthy plants exist side by side, but it is easy to produce a wilted branch as well as vigorous growth on the same plant at the same time. This phenomenon occurs if a branch is left at the first cut in June to maintain the transpiration current. The result of this is that the damage to the fine roots and nodules (as shown by root washings) is less than if the plant is completely cut back while the new shoots are formed much more quickly. It often happens in such cases that after the new growth is well established near the ground, the old branch left begins to show signs of wilt which, however, does not spread to the new shoots. This is probably due to the utilization of the crude sap by the new growth near the ground level and the consequent slow starvation of the upper branch.

Both during the early and the late rains, deep cultivation has the effect of producing wilt. Two well-marked cases of this have occurred at Pusa recently. In 1918, Java indigo, sown in double lines to admit of interculture during the monsoon, steadily lost in vigour compared with the broadcast crop side by side and also developed more wilt. In the present season, 1919, the experiment was repeated with four types of indigo and on different classes of land. In most cases, the indigo grown in double lines with interculture yielded less green plant and also developed more wilt than the neighbouring broadcast plots. The effect of the cultivation was found to destroy the lateral roots near the surface and to stimulate root formation in the deeper soil layers. The lower roots were destroyed by poor soil aeration and the plants therefore developed wilt.

Wilt is easily produced after the rains during October and November by the cultivation of old indigo which has hitherto managed to survive at this period, the only active roots are close to the surface and the indigo plants are dependent on these. Cultivation or the natural drying of the surface soil destroys the surface roots and wilt occurs. It can be prevented by mulching such plants with straw or dried grass after the sowing rains in October. The mulch preserves the moisture and so assists the surface roots to maintain the indigo till growth ceases during the cold whether.

In 1919, a comparison was made between mulched and non-mulched plants. The former held their leaves and resisted wilt while the latter were affected by the trouble.

The artificial production of wilt. Wilt can be artificially produced in the following ways :—

(*a*) By mutilation of the root system.

(*b*) By cutting back young rapidly growing August sown plants in October, when the reserve materials in the tap-root are insufficient for root regeneration.

(*c*) By October and November cultivation of old indigo dependent for its crude sap on superficial roots.

(*d*) By complete cutting back in the cold weather, when the root regeneration of surface-rooted types is difficult on account of the low soil temperature.

(*e*) By waterlogging slowly from below during the rains by closing the drainage openings of lysimeters.

Undoubted wilt has been produced by root mutilation in two cases. The first occurred in a plant which was pruned on June 21st, 1919. The roots were exposed on July 15th, and found healthy in all respects. Before replacing the soil, the tap-root was severed at a depth of one foot below the surface and most of the fine roots were destroyed. Wilt developed. The second example occurred in the case of a plant which was pruned on June 21st, 1919. The roots were exposed on August 5th and were found to be normal. Before replacing the soil, all the fine roots and nodules on the laterals were removed to a depth of one foot but the tap-root was left intact. Wilt rapidly developed and when the root system was again exposed on August 29th, very few active roots were found.

The complete cutting back, about mid October, of young actively growing August sown indigo is certain to result in numerous cases of wilt. In 1914, three plots of August sown indigo, each a quarter of an acre in area, were cut back about the middle of October. Most of the plants died but a certain number produced weak wilted shoots. Root regeneration was found to be practically impossible due to the lack of reserve materials in the young roots. In another plot, plants with larger roots, when cut back at a later period, shot normally. These experiments have been repeated several times since with similar results.

Another method of producing wilt is to cut back tall August sown plants during the cold season, when the temperature of the soil is too low for root regeneration to take place easily. In December 1918, a number of lines of very healthy well-developed August sown plants were cut back when over five feet high. It was found the following February that the new growth

exhibited all stages from healthy to wilted foliage. Counts were made on February 17th, 1919, with the following results (Table III).

TABLE III.

Effect of cutting back indigo in the cold weather.

No. of row	No. of plants cut back	Badly wilted	Partly wilted	Normal
1 ..	205	31	72	102
2 ..	176	50	47	79
3 ..	136	46	36	54
4 ..	124	35	30	59
TOTAL ..	641	162	185	294

Thus more than half the plants cut back developed wilt.[1] A number of root washings were made and in all cases wilt was found to be associated with the practical absence of root regeneration. These plants were kept under observation till April, by which time a remarkable change had taken place. The rise in the soil temperature in March and the improvement in the aeration of the soil caused the wilted plants to recover; root regeneration took place and the growth became normal.

Perhaps the most interesting case of the artificial production of wilt took place during the rains of last year. At the beginning of the monsoon of 1918, Java indigo was grown in two sets of lysimeters. These were air-tight cemented tanks 1/1000 of an acre in area, four feet high, built about the ground level and provided with drainage openings which could be closed at will. In one set, alluvial soil obtained from the Kalianpur farm near Cawnpore was used, in the other set, light Pusa soil was employed. Kalianpur soil is exceedingly rich in available phosphate (0·318 per cent) while Pusa soil, when analysed by Dyer's method, gives very low figures for available

[1] The plants which developed wilt were those which had their laterals near the surface, the deeper-rooted plants produced normal growth. Thus the monsoon results are reversed during the cold weather. The explanation is simple. In the cold weather, the factor which checks root regeneration is low soil temperature. This affects surface-rooted plants much more than deep-rooted types.

phosphate (0·001 per cent). The results obtained may be summed up as follows :

(*a*) In both Pusa and Kalianpur soil, the indigo in the lysimeters with free drainage escaped wilt.

(*b*) When the drainage openings were closed and waterlogging from below took place, all the plants were wilted in both Kalianpur and in Pusa soil.

(*c*) The wilt in Kalianpur soil (rich in available phosphate) was much worse than in Pusa soil (said to be low in available phosphate).

(*d*) The growth in Kalianpur soil was much slower than in Pusa soil.

Recovery from wilt. Cases of complete recovery from wilt occur frequently. Good examples occurred during the rains of 1919. As previously mentioned, wilt first made its appearance this year between July 23rd and August 7th, and again during the first three weeks of September. After the first attack, which was slight, it was observed that plants frequently recovered and after showing wilted foliage produced normal shoots. The roots of two plants which recovered from wilt were exposed on August 21st, and were found to have produced numerous new healthy roots. This regeneration was evidently due to improved soil conditions. In one of the two cases examined, a branch, which showed wilted foliage, continued to grow in length and to form healthy leaves. This does not often occur in cases of recovery. As a rule, the wilted branches die and new healthy shoots are produced.

A second interesting case of recovery from wilt on the large scale occurred in March, 1919, in the case of two plots, which were badly affected at the end of the previous monsoon. Both plots, however, showed a remarkable recovery in March and April 1919. The diseased plants commenced to grow and the shoots and roots formed were perfectly healthy. Similar results were obtained in a plot of Type 15, which had yielded two heavy crops of leaf during 1918. Many of the plants were attacked by wilt during the cold weather of 1918–19, but there was a remarkable recovery in March and April of 1919. The new growth was abundant and healthy and so vigorous were some of the individuals that they survived the monsoon of 1919, and at the present time, October 1919, promise to give a second seed crop.

The most striking cases of recovery from severe attacks of wilt occurred in the lysimeter experiments of 1918. In two cases, in lysimeters which had been waterlogged from below during the rains and in which all the plants were

exceedingly badly wilted, complete recovery took place in March 1919, when the stunted diseased individuals which had been looked upon as dead, threw out vigorous healthy shoots.

Conclusions.

These are the facts relating to the occurrence and production of wilt so far as they have been ascertained under Bihar conditions. The conclusion is irresistible that the trouble results from the destruction of the roots and nodules under circumstances when regeneration is impossible. Under estate conditions, the indigo crop, with very rare exceptions, does well till the first cut. This operation, however, destroys the fine roots and nodules, and before new growth can take place root regeneration is necessary. If the soil aeration is sufficient at this period, the plant shoots well and, provided these conditions continue, as in 1919, an excellent second crop follows. If, however, at the time of the first cut, floods cause the ground water to rise and if heavy rain waterlogs the surface soil for long periods, root regeneration is very difficult and the result is wilt and a poor second cut. The wilt which often attacks old indigo in November and December is due to the fact that this plant has been forced to develop surface roots in the late rains. These suffer from want of water as the ground dries after the monsoon and the advent of the cold weather prevents the formation of more roots.

Confirmatory evidence.

If our view of the cause of wilt is correct and if the aeration of the soil is really defective in Bihar during the second half of the rainy season, several consequences naturally follow. Firstly, wilt should not be confined to Java indigo, but should affect other deep-rooted plants while surface-rooted species, on the other hand, should escape. In the second place, as two rainy seasons in India are never the same and long breaks occur, soil aeration in Bihar in August and September should occasionally improve and lead to the recovery of wilted plants and to greatly increased crops of indigo. In the third place, indigo wilt should not occur *in other localities* provided the soil ventilation is efficient during the whole of the monsoon phase. Confirmatory evidence has been obtained in all these directions.

Wilt in Bihar during the monsoon is by no means confined to Java indigo. It is common on many deep-rooted varieties of *patwa* (*Hibiscus cannabinus* L.) and *sann* (*Crotalaria juncea* L.) while shallow rooted types of these two species are little affected. Further, surface-rooted species like Roselle (*Hibiscus Sabdariffa* L.) thrive no matter how wet the monsoon may be. The differ-

ences between the distribution of the roots of Roselle and of deep-rooted types of *patwa* are shown in Fig. 3, while in Fig. 4 the roots of an early and late type

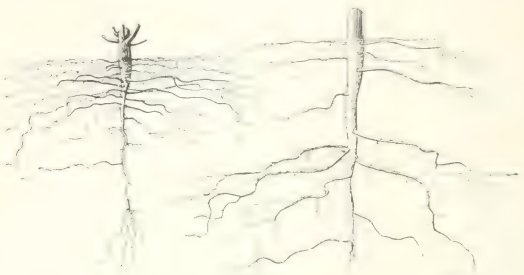


FIG. 3. The root system of *Hibiscus Sabdariffa* (left) and *H. cannabinus* (right).

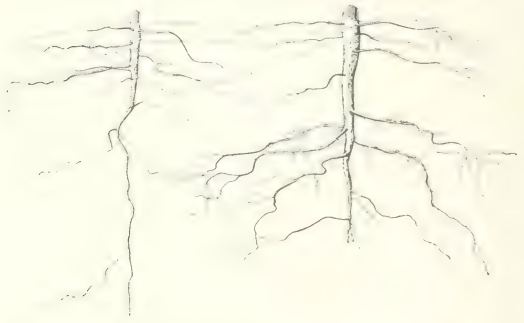


FIG. 4. Early (left) and late (right) types of root systems in *H. cannabinus*

of *patwa* are illustrated. The surface-rooted Roselle crop and the early types of *patwa* do well at Pusa even when the soil is waterlogged. The deep-rooted types of *patwa* in such seasons, on the other hand, suffer severely from wilt. Similar results are obtained in the case of *sann* varieties. The local Bihar variety with surface roots sets seed but the deep-rooted tall variety from the

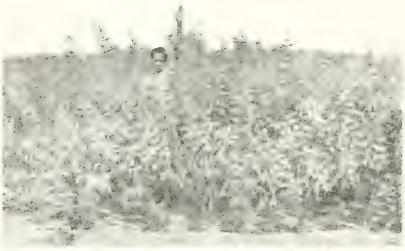


Fig. 1. INDIGO ON BHATA

Fig. 2. INDIGO ON BLACK SOIL.

black soils of the Central Provinces suffers from wilt and hardly yields any seed. Thus the deep-rooted varieties of *patwa* and *sann* behave exactly like the deep-rooted varieties of Java indigo and are severely attacked by wilt in the late rains. Roselle and the shallow rooted types of *patwa* and *sann* on the other hand escape wilt.

The general experience of 1919 affords considerable support to our views on the cause of wilt in indigo. For several years past, the rainfall has been heavy and floods have been the rule. Indigo has not done well and wilt has been common. The year 1919, however, was a year of short rainfall combined with the absence of floods. In consequence, the rise of the subsoil water was not considerable. The soil aeration was, therefore, above the average. Slight wilt occurred on two occasions only but the plant rapidly recovered. Three cuts of indigo were obtained at Pusa and the old plant is now exceedingly healthy after the rains. Many of the Bihar estates, particularly those which are most liable to waterlogging, did remarkably well in 1919, and for the first time for many years have reaped an excellent second cut. Although the area under indigo in Bihar in 1919 was 14 per cent less than in 1918, the outturn is expected to be greater than in 1918. Such a result would not be possible if the Bihar soils are suffering from depletion of one of the essential constituents of the soil solution.

Indigo wilt is not met with during the rains in India on porous soils where the aeration is efficient. This interesting fact has been studied in two cases—at Dehra Dun in the submontane zone and at Chandkhuri in the Chattisgarh Division of the Central Provinces. At Dehra Dun, the monsoon rainfall is very high, often more than 100 inches. At the Harbanswala Tea Estate, where Java indigo was grown for some years, there is excellent surface drainage and the soil is remarkably porous, so permeable in fact that it is possible to walk over the fields a few hours after five inches of rain have been received. Here Java indigo grows with great rapidity, the plants are at least ten feet high and no signs of wilt can be detected. At Chandkhuri near Raipur in the Central Provinces, the results were similar. Grown on the porous laterite soils (*bhata*) under a maximum rainfall of over 60 inches, Java indigo thrives remarkably and no trace of wilt is to be seen[1]. Good crops of seed are produced although the soil is particularly poor in total and available phosphoric acid. When grown on the stiff and poorly aerated but richer black soils under similar rainfall and similar climatic conditions, Java indigo develops much more slowly, (Plate V).

[1] Clouston, D. and Padmanabha Aiyar, A.R., *Agr. Journ. of India*, Special Indian Science Congress Number, 1918, p. 89.

III. The degeneration of Java indigo in Bihar.

It has been shown above that wilt during the monsoon phase in Bihar is due to the destruction of the fine roots and nodules at a time when regeneration is difficult on account of poor soil aeration. This, however, does not explain why the crop gradually became susceptible to wilt and why the soil aeration factor should destroy the crop in say 1914, and should have had little or no effect twelve years earlier. As is well known, the earlier consignments of selected seed obtained from the estates of the Dutch planters in Java gave excellent results. The plants grew well and gave at least three cuts of leaf, followed by high yields of seed. On several estates, the crop behaved as a true perennial and gave cuts of leaf during the second monsoon. Slowly the size, vigour and seed producing power of the crop fell off and wilt made its appearance in the late rains in increasing amounts. By 1914, the area had decreased to 15,000 *bighas*. The progressive degeneration of the indigo crop has been found to be due to a gradual change in the gametic constitution of the crop which has been in progress since Java indigo was first introduced into Bihar. The evidence on which this conclusion is based has been arrived at from an investigation of the methods of pollination and fertilization of the indigo plant, a botanical examination of Natal indigo from which the Java plant was originally developed, a detailed study of the various indigos now grown in Java and of the constitution of the crop as cultivated in Bihar.

Pollination and fertilization.

All the species of indigo we have examined at Pusa, including Natal indigo and the various kinds now growing in Java, rarely set seed under net. The floral mechanism is of the ordinary explosive type designed to ensure crossing. Fertilization in Bihar is almost entirely brought about by insect visitors, the chief agents being two common Indian bees (*Apis florea* and *Halictus gutturosus*). Even in a single generation from self-fertilized seed there is a marked falling off in the size and vigour of the offspring so that both self-sterility and natural cross-fertilization have to be considered in any improvement by selection.

Natal indigo.

Java indigo was originally introduced into Java from Natal, where it was found growing in the wild state. Java indigo, as grown by the Dutch planters, is, however, quite a different plant from the wild indigo of Natal, and is said to have arisen by crossing between Natal indigo and one of the species formerly cultivated in Java. In 1913, through the good offices of the Hon'ble Mr. F. B,

Smith, Secretary for Agriculture to the Government of the Transvaal, the seeds of single plants of the wild indigo of Natal were separately collected in that country for growth at Pusa. The samples were sown separately in lines next to next and the progeny was examined. The rows were remarkably uniform in themselves and there were no great differences to be observed between the various lines. Natal indigo proved to be erect in habit with little branched, green stems and a deep root system. The foliage was somewhat sparse. The reddish stems and leaves and the much branched habit of many of the types found in Java indigo were entirely absent. As regards susceptibility to *Psylla* and wilt, the Natal plant showed far less resistance than the Java cultures growing side by side.

The kinds of indigo now grown in Java.

In 1916, a collection of the various kinds of indigo now growing in Java was obtained through the kind assistance of Dr. Koch of the Buitenzorg Botanical Gardens. These consisted of the following samples—Java-Natal indigo from the Koeto Sani Estate, Java indigo from Soerabaya, Natal indigo from Soerabaya, Bengal indigo, wild indigo, Presi indigo, Sumatrana indigo and *Indigofera suffruticosa*. These were grown at Pusa in plots side by side and their behaviour under Bihar conditions, and after cutting back, was carefully studied. In most cases, the root system was also examined. The range in general habit, in the size of plant, in root development, in the proportion of leaf to stem, in vegetative vigour, in the power of repair after cutting back was very great. Some were perennials and others proved to be annuals. Wild indigo and Presi indigo showed low vegetative vigour and little power of repair after cutting back, behaving very much like Sumatrana indigo. Natal indigo grew like the species obtained from Natal and showed itself to be a deep-rooting perennial, unsuited, however, on account of its deep root development, to Bihar conditions. The sample which most nearly resembled the old Java plant which did so well in Bihar, was the Java-Natal from the Koeto Sani Estate. The examination of the plants raised from these samples showed that there are many types of indigo now growing in Java only one of which was in the least suited to Bihar conditions.

The composition of the Java crop in Bihar.

In 1916, the botanical composition of the Java crop, as grown in Bihar, was examined in detail and compared with Java indigo as it existed in 1905 eleven years earlier. By a fortunate circumstance, we grew several plots of Java indigo at Pusa, in 1905 and 1906, and thus became familiar with the plant which

at first did so well in Bihar. To enable the changes in botanical composition which have taken place in recent years, to be understood, some reference to the methods of seed supply in Bihar is necessary. Up to very recent years, the method of raising seed in vogue was to allow the best of the fields to flower after the second cut of leaf was taken in August. This involved the production of seed from plant greatly diminished in vigour, both by the growth of two cuts of leaf and by the unfavourable soil conditions set up by the monsoon. The result was insufficient seed and moreover the wrong type of seed. This arose from two causes. In the first place, the early, rapidly growing types in the mixture flowered in September and early October, when the air was too damp for fertilization to take place. These naturally became suppressed. Consequently, the bulk of seed was obtained from the later deep-rooting types. The method of seed growing, therefore, rapidly altered the botanical composition of the crop and favoured deep-rooting unthrifty types. A shortage of seed resulted which necessitated a considerable amount of importation. At first, this was obtained from Java, not however, from the Dutch planters, who had by this time practically given up indigo, but from the natives who naturally paid no attention either to the type or to selection. It was no surprise, therefore, to find in 1916, that the Java crop in Bihar contained such an extraordinary range of types. It consisted of every gradation between rapidly-growing surface-rooted annuals and slow-growing deep-rooted perennials. The range in the type of foliage and in the proportion of leaf to stem was considerable. Weak, procumbent types like the wild indigo of Java, were met with as well as forms resembling Presi indigo. Besides, a host of intermediates occurred which, when sown separately, yielded a wide range of types. Examination of the plants raised from a sample of seed from Java, imported by one of the planters in 1916, showed that the admixture of forms was even greater than that met with in the ordinary Bihar crop. The only conclusion that could be arrived at was that the natives of Java, who for many years had been supplying the Bihar planters with their indigo seed, had been in the habit of growing together all kinds of indigo found in Java and that a great deal of natural crossing had taken place in consequence. In the process, the original type grown by the Dutch planters had become altered almost beyond recognition. The methods of seed growing in Bihar and the entire absence of selection did nothing to improve matters.

These facts and observations fully explain the degeneration which has taken place in Java indigo. While continuous selection was practised by the Dutch planters a type of plant suitable for growth in heavy rice soils was maintained and this seed naturally did well under Bihar conditions and was

able to survive the rainy season. The stoppage of selection, the mixing of kinds which is such a characteristic of native agriculture and the resulting crossing with types which do not suit Bihar soon completely altered the botanical composition of the crop and rendered it unsuitable for growth under monsoon conditions. Indigo wilt is, therefore, another example of degeneration through vicinism.

IV. The remedies against wilt.

Now that the nature and cause of wilt have been discovered, the question of remedies can be considered. Wilt has arisen from unrestricted natural cross-fertilization which, in the course of time, has completely altered the original type which did so well in Bihar. This crossing with annuals combined with the complete cessation of selection has lowered the general vigour of the crop, has rendered it much more susceptible to waterlogged conditions and has altered the type of root-system. The problem is now to recover by selection the original type which suited Bihar conditions and to *maintain it by continuous selection.* The maintenance of the type will probably prove to be the most difficult portion of the work.

Java indigo only sets seed if visited by bees and the crop is a mass of freely crossing heterozygotes. If grown from self-fertilized seed, there is a rapid loss of vigour through self-sterility. The ordinary methods of selection, therefore, do not apply. Crossing can only be controlled, it cannot be prevented. To maintain the type required, constant selection will be essential and the greatest attention will have to be paid to seed growing. The present practice of importing into Bihar any kind of seed which happens to be offered for sale, will have to be given up and arrangements will have to be made to grow all the seed required locally and to carry out the necessary selection on the estates themselves.

Selection.

A considerable amount of selection work has been done on the ordinary indigo crop and on the samples obtained from Java. Several of these selections have already been tested on an estate scale. Three types have survived the early trials and have been retained for further work. These are as follows :—

Type 10. A mixture of quick growing early maturing forms selected from the seed imported from Java in 1916. The selection work in progress on this type promises to isolate a type of Java indigo which might replace Sumatrana. Sufficient seed has already been obtained for trials on an estate scale which have been arranged for.

Type 15. This is a somewhat bushy indigo with surface roots which shoots well after the first cut and which seeds well in Bihar. It is now being

grown successfully on several estates and is being further improved by selection at Pusa.

Type 20. This has been selected from the Java-Natal indigo obtained from the Koeto Sani Estate in Java. It is a tall rapidly growing perennial indigo which resembles the original Java-Natal first introduced into Bihar. A number of plants of the original sample have given two crops of seed and have survived the intervening monsoon. Selection is in progress on this type by which the vigour is being increased and by which the power of repair after cutting back is being improved.

As the soil conditions of the various indigo estates in Bihar vary considerably, it is quite possible that one type of plant will not prove to be the most efficient in all cases. The soils of most of the estates in the northern portion of the indigo tract are heavier and moister than those of the south. Different types may, therefore, be required for the various tracts. Should this be found to be the case, it will add considerably to the labour of selection.

Improved drainage.

As poor soil aeration has been found to be an important factor in the well-being of the indigo crop, it follows that any improvement in the general or local drainage of Bihar during the rains would tend to reduce wilt. Regarded in its widest aspect this is a large subject as the efficiency of the local rivers, on which the monsoon drainage is based, depends on the rise and fall of the Ganges, on the area under inundation in Bengal and on the obstructions (in the shape of embankments) to surface drainage in Bihar. The wider aspects of the subject, however, demand attention as there can be no question that the flood level in Bihar is rising and that the damage done to the monsoon crops is increasing. Improvements in local drainage are in many cases possible by the adoption of the Pusa system, a method which has been taken up already on a number of estates.[1]

Appendix.

Variation of CO_2 in the soil gas from the different plots in the Botanical Area, Pusa, during the period January to November 1919.

Apparatus and methods employed.

A hole was first made in the plot by means of a half-inch auger. A brass tube (2 feet 3 inches in length, inner diameter 0·6″) sharpened at one end with

[1] *Bulletin* 53, *Agr. Res. Inst., Pusa*, 1915.

holes $\frac{1}{8}$" in diameter on its side every half-inch apart up to a length of 6" from the sharpened end, was driven firmly into the soil at an angle of about 30°, so that the end of the tube penetrated to a depth of about 12" from the surface. Three inches of the tube remained outside the soil. The open end of the tube T outside the soil was connected by means of a rubber stopper R and a tap

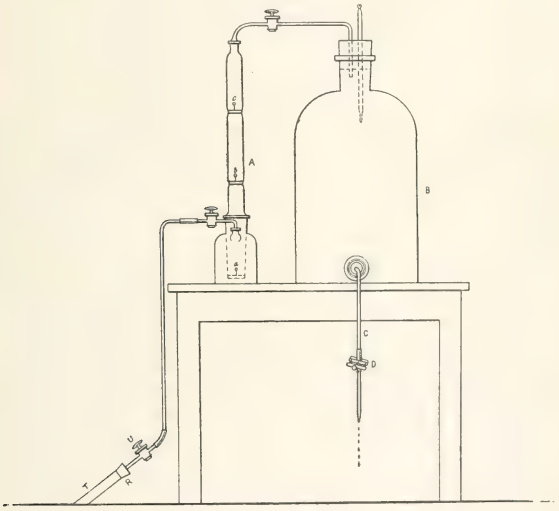


FIG. 5. –Apparatus used in determining the amount of carbon dioxide in the soil atmosphere.

U to a capillary tube V to a Reiset's apparatus A, containing a measured volume of baryta water of known strength. The Reiset's apparatus was connected to a 15 litre aspirator bottle B filled with water. The aspirator bottle was graduated by means of a paper scale to $\frac{1}{2}$ litres. Soil gas was aspirated through the apparatus by allowing the water to flow by means of the exit tube C attached

to the aspirator. The flow of the gas was regulated by means of the screw clip D and was kept at about 3 litres per hour. Before opening the tap T all the connections were tested for leakage. On opening the tap T, soil gas passes through the baryta solution which absorbs the CO_2, forming barium carbonate. The three perforated silver cones, a, b and c in the tower of the Reiset's apparatus allow complete absorption of the CO_2 by the baryta solution. About 10 litres of soil gas were aspirated in each case. At the end of each experiment, the volume of gas and the temperature (indicated in the thermometer in the neck of the aspirator bottle) were noted, the tap T was closed, and the apparatus disconnected and brought to the laboratory. The baryta water from the Reiset's apparatus was filtered quickly, filled into a burette, a measured portion run out and titrated against standard acid. The strength of the baryta water used was determined once previous to the aspiration of soil gas and the difference in strength after aspiration gave the measure for calculating the amount of CO_2 contained in the soil gas. By this method, the amounts of CO_2 in the soil gas from (1) grassed down, (2) grassed down but partially aerated by trenches and (3) cultivated plots, were determined once every month and the results obtained are given in Table II and Plate I.

Results.

The results at once show that the CO_2 has been consistently high in the grassed plot and low in the surface cultivated plot; the trenched plot being intermediate between the two as regards CO_2 content. During the first three months, January to March, whereas the grassed plot had shown practically no improvement, the other two showed a marked falling off in the CO_2 present with the lowering of the water-level. During May and June, when the weather was hottest and when the water-level was its lowest, the CO_2 content in all the three plots was also lowest. With the advent of the monsoon and a fair amount of rainfall, all the plots showed a considerable rise in the amount of CO_2 present in the soil gas—the increase being about four times as much in grassed and trenched plots, and one and a half times as much in the cultivated plot. From July to September, coincident with the increase in rainfall and the consequent rise of the water-level, there has been a regular rise in the amount of CO_2 in the soil gas from all three plots. The October and November figures show a marked fall in the amount of CO_2 in all three plots.

November 17th, 1919.

JATINDRA NATH MUKHERJEE.
First Assistant to the Imperial Agricultural Chemist, Pusa.

PART II.

THE FACTORS UNDERLYING THE SEED PRODUCTION AND GROWTH OF JAVA INDIGO IN BIHAR.

I. Seed production.

In 1913, when we took up the investigation of Java indigo in Bihar, the seed problem was acute and the industry was in danger of extinction from this cause alone. The supplies had fallen so low that they were insufficient for sowing while the price had reached a point which seriously reduced the margin of profit.

The method of raising indigo seed in vogue in 1913, was to allow the best of the fields to flower after the second cut of leaf was taken in August. This involved the production of seed from plant greatly diminished in vigour both by the growth of two cuts of leaf and by the unfavourable soil conditions set up by the monsoon. The result was insufficient seed and moreover the wrong type of seed. This arose from two causes. The early, rapidly growing types in the mixture flowered in September and early October, when the air was too damp for fertilization to take place. The bulk of the seed was obtained from the later deep-rooting types. This method of seed growing, therefore, adversely altered the botanical composition of the crop. The shortage of seed which resulted necessitated a considerable amount of importation. At first, this was obtained from Java, where the supply for Bihar was grown by the natives, who naturally paid no attention either to the type or to methods of selection. In recent years, supplies have been purchased from Assam and the United Provinces, and indeed from any locality in India which happened to have indigo seed for sale. The feature of these external seed supplies was the entire absence of selection of forms suitable for Bihar conditions.

The results of our investigation on wilt show that the type of indigo required in Bihar is a surface-rooting, rapidly growing plant which is also resistant to waterlogging. As Java indigo is a mass of heterozygotes and as the range of possible forms is very great, it follows that it is not sufficient merely to isolate a suitable type by selection. The type must be maintained

by continuous selection or a repetition of the wilt problem is inevitable. To achieve this object, the seed must be grown in Bihar and the annual selection necessary must be carried out locally. Thus the raising of seed is a matter of the very greatest importance to the future of the indigo industry.

The factors underlying seed production.

The solution of the problem of seed production was found to lie in the growing of a special seed crop and in obtaining the seed from the most vigorous plants. This was accomplished by sowing the seed crop in early August by which time the rains were half over. Provided high lying land in good condition with excellent surface drainage is selected and attention is given to surface cultivation, the seed crop can be established even in the wettest years. At first, growth is slow and root-development is largely confined to the upper layers of soil. As the level of the ground water falls, the soil aeration improves and the roots invade the deeper layers. By October the crop is established and growth then becomes rapid. The yield of seed has been found to depend on two factors—fertilization and the rapid growth of the plant.

Fertilization. The conditions necessary for fertilization were found to be temperature and humidity. In Bihar, indigo can be made to flower at almost any period of the year but it only sets seed if the temperature and humidity are both favourable. In September and early October, the air is too damp for setting to take place and although flowers and pods form, practically no seed is obtained. In December, it is too cold for fertilization.

The best period in the year is the six weeks between October 15th and November 30th, when the weather is warm and dry. At this time, fogs and rain are practically unknown. Bees are very active during this period when, other things being favourable, practically every indigo flower is visited and yields good seed. For all the flowers to be worked over, the plants must be properly spaced and allowed to branch freely. Anything in the nature of overcrowding prevents proper branching and also keeps the air round the plants too damp. It is best, therefore, to grow the crop in lines, about three feet apart, and to attend to spacing in the rows from the very beginning. The plants should be well forward by the middle of October, so that flowering begins about this time. Any great delay means a reduced yield of seed.

Rapid growth. It is obvious that the production of a heavy crop of seed necessitates a large and vigorous plant. This is only possible if the soil conditions are maintained at the optimum. The fields selected must be high lying, above the flood level and the surface drainage must be good. The

soil must be rich in organic matter to provide the nitrogen needed for rapid growth and also to preserve the soil texture during the late rains of August and September. After the last showers at the beginning of October, the soil between the rows must be deeply cultivated to supply the roots and nodules with abundant air. Thus organic matter, surface drainage and aeration are the chief soil factors which require attention. The importance of surface drainage needs no proof—in its absence in a wet season there is no crop.

In the investigation of the effect of aeration and organic matter on seed production, a modified method of pot culture[1] was adopted. The pots consisted of pits, 3 feet square and 18 inches deep, filled with soil diluted with various aerating materials or mixed with various manures. The pits thus act as culture pots. If prepared before the rains, the soil settles down and by August are ready for sowing with indigo. In this way, many difficulties are avoided such as the water-supply and the effect of temperature. Periodical measurements of the height are made, determinations of the soil moisture and available nitrogen are carried out and after the seed is harvested, the weight of dry stem, less the leaves, is recorded. The results are set out in Table I.

[1] *Agr. Jour. of India*, Special Indian Science Congress Number, 1918, p. 36.

TABLE I.

The effect of soil aeration and organic matter on the seed production of Java indigo.

Soil treatment	No. of plants	Average heights of plants in cm.										Weight of dry produce in grammes corrected for 50 plants	
		Oct. 10	Oct. 23	Nov. 3	Nov. 13	Nov. 23	Dec. 3	Dec. 13	Dec. 23	Jan. 2	Feb. 1	Feb. 21	Stems excluding leaves	Seed
Control	49	4·4	7·7	11·9	15·5	20·3	24·5	25·9	25·8	26·7	28·1	27·2	68	32
Soil $\frac{1}{2}$ + Sand $\frac{1}{2}$	50	4·3	6·9	11·5	17·4	23·7	28·9	31·6	33·5	34·1	35·6	35·0	127	70
Sodium nitrate @ 8 cwt. per acre ..	50	4·9	8·9	16·0	23·3	30·4	38·3	42·1	43·2	42·7	43·5	42·7	191	115
Soil 7/10 + potsherds 3/10 ..	50	4·5	9·2	14·5	19·9	26·6	30·6	33·0	33·9	34·7	34·6	33·5	136	89
Soil 8/10 + potsherds 2/10 ..	50	5·2	8·4	13·4	18·1	23·6	28·6	30·4	32·1	32·9	33·6	33·6	141	94
Soil 9/10 + potsherds 1/10 ..	49	4·4	7·7	12·5	17·1	22·8	27·4	28·8	30·3	32·4	32·4	31·1	118	92
Soil 7/10 + leaf-mould 3/10 ..	50	11·2	23·4	40·8	54·6	70·4	79·3	81·1	82·7	83·2	83·6	83·7	907	577
Soil $\frac{7}{10}$ + leaf-mould $\frac{1}{10}$ + potsherd $\frac{2}{10}$ ..	50	12·8	25·8	43·3	56·9	67·3	74·4	74·9	77·8	75·8	76·7	76·1	715	485
Soil $\frac{8}{10}$ + leaf-mould $\frac{1}{10}$ + potsherds $\frac{1}{10}$ ..	49	12·2	24·3	41·1	54·4	66·5	73·7	76·9	77·6	77·6	80·5	78·3	905	595
Soil $\frac{9}{10}$ + leaf-mould $\frac{1}{10}$ + potsherds $\frac{1}{10}$ ..	50	14·9	28·3	44·7	54·7	67·3	74·2	76·1	75·8	77·6	77·0	76·9	744	511
Control	48	3·8	6·2	9·4	12·3	16·1	19·1	21·0	21·3	23·3	24·3	24·4	72	32

An examination of the table discloses several interesting facts. As regards growth and seed formation, improved aeration by itself has had a marked effect. Seed production was increased nearly three times and growth was almost doubled by the substitution of ten per cent of the volume of soil by potsherds. The replacement of half the soil by sand led to a similar result. The greatest effects, however, were produced by leaf-mould with or without potsherds. The replacement of forty per cent of the volume of the soil by leaf-mould (30 per cen) and potsherds (10 per cent) increased seed production twenty-one times and growth more than tenfold. These results have been frequently confirmed both in the field and in other series of pot cultures. The effect of temperature is shown by the falling off in the rate of growth which took place in all the pots after the end of November, no matter what the treatment. This always happens in the case of Java indigo at this time. After the end of November, no matter what the size of the plant may be there is practically no growth and no setting takes place during the cold months of December, January and February unless the temperature is much above the normal.

An improved method of seed growing.

The discovery of the factors underlying seed production enabled us to devise an improved method of growing indigo seed in Bihar. Instead of raising seed after leaf from a partially exhausted plant, it was found better to reverse the process and to raise a special seed crop which afterwards could be kept for leaf. For this purpose, the seed is sown early in August on specially selected high lying fields, known as *dee* fields. These fields must be above the flood level and they must have excellent surface drainage. They should lie, if possible, near the banks of rivers so that the aeration of the soil is improved as quickly as possible when the water-level falls in September and October. To enable rapid growth to take place and to preserve the soil texture during the rains of August and September, the land must be well manured the previous May or June, with decayed organic matter and afterwards worked as a clean fallow. The crop should be sown in lines about three feet apart and particular care must be taken during the rains to break the surface crusts formed by rain as often as possible. This frequent harrowing is essential as the seedlings of Java indigo are very susceptible to poor soil aeration and are easily killed by surface crusts. After the last rains at the beginning of October, a final harrowing is necessary, followed by deep cultivation between the lines to provide copious aeration for the intense nodular development then in progress.

In addition to correct soil management, the object of which is to raise a large strongly growing plant by flowering time in mid October, particular

attention must be paid to thinning and selection. A good deal of natural selection takes place by the extinction, through poor soil aeration, of many of the deep-rooted constituents which naturally result from the gametic constitution of the crop. It is always found that many of the deep-rooted unthrifty plants either die out altogether or lag behind the surface-rooted types. All small weak plants which survive should be destroyed from time to time, and the crop at flowering time should consist only of the type required. The best plants are those which branch copiously and which also flower early. After flowering has set in, a final thinning is required to eliminate those individuals which, although of suitable habit, show a tendency to flower too late.

The result is a magnificent crop of seed which in good years weighs out well over half a ton to the acre. Even in the worst years at Pusa, the yield has not fallen below a quarter of a ton to the acre. The seed produced is heavy and well matured and far superior to anything produced elsewhere. It germinates strongly and evenly and the resulting crops do well. As the yield of seed varies considerably with the season, estates should hold about half their annual seed requirements in reserve so as to make up for any deficit in a year of late floods. Indigo seed retains its germinating power for several years if thoroughly dried before storage in the air-tight seed bins devised by the Botanical Section at Pusa which are now on the market in India.

This improved method of seed growing has been successfully adopted on several of the indigo estates in Bihar and during the present year 1919, excellent crops are to be seen. August sowing in Bihar will by itself improve the type of indigo as it helps to eliminate the deep-rooting unthrifty types susceptible to wilt and favours the shallow rooted quick growing wilt resistant forms. Hence the importance of producing all the indigo seed required in Bihar itself and the discontinuance of the practice of importation from outside sources where natural selection does not operate to anything like the same extent.

II. The growth of Java indigo.

While the investigation of the wilt disease and of the factors underlying seed production were in progress, attention has been devoted to the conditions necessary for the growth of the ordinary indigo crop. A large amount of work has been done on this side of the question and several improvements in cultivation have resulted. The growth of the indigo crop, other things being equal, has been found to depend mainly on two factors—soil aeration and organic matter.

Soil aeration.

From the time the ordinary crop is sown in September or early October to the following May, indigo shows a remarkable response to soil aeration. After germination and while the seedlings are small, anything in the nature of a surface crust is fatal and constant harrowing is essential. During the cold weather and the hot months of March, April and May, indigo shows a remarkable response to repeated harrowings with the lever harrow. These implements were originally introduced into India by the Botanical Section of the Pusa Institute and are now widely used on the indigo estates. They enable the surface soil to be broken up to a depth of nearly two inches and the mulch produced preserves the soil moisture during the hot weather. In addition, aeration is improved and the large supply of air needed by the intense nodular development which takes place at the break of the rains, is provided for. During the early monsoon, soil aeration is maintained by the rainfall which is a saturated solution of oxygen and experiments show that cultivation at this period is unnecessary and does more harm than good. In the later rains, the marked aerotropism of the roots (caused by the rise of the gases of the deep soil layers which follows the upward movement of the ground water) combined with the destruction of the absorbing root system of the subsoil, places cultivation out of the question. This should, therefore, stop at the break of the rains in May.

In addition to improved aeration by means of surface cultivation, the indigo plant shows a marked response to a more open soil texture and also to the aeration of the subsoil. As an example of the effect of altered soil texture the results obtained on growth by the addition of sand or potsherds to the soil are of interest. (Table II.)

TABLE II.

The effect of improved soil aeration on the growth of indigo.

Kind of soil	No. of plants measured	Average length in cm.	Percentage increase
Soil only	33	36·7	.
50% soil 50% sand	36	54·6	49
90% soil 10% potsherds ..	33	48·3	31
70% soil 30% potsherds ..	35	50·9	38

The substitution of only ten per cent of the volume of soil by inert potsherds sufficed to increase growth by over 30 per cent.

Equally striking are the results obtained by waterlogging the subsoil before the indigo crop is sown. The effect of waterlogging the heavier soils at Pusa during September, has been found to result in extensive losses of

nitrogen through denitrification. In September 1917, a somewhat stiff piece of land was waterlogged for a month and sown with Java indigo the following October. The effect of the waterlogging on this leguminous plant was very marked. Five months after sowing, equal areas on the waterlogged and control plots were taken and the heights of the plants were measured. On the waterlogged plot, the average height of 200 plants was 10·5 cm.; on the control, the average height of an equal number of plants was 28·0 cm. When the root system of the plants on these plots was examined, it was found that the first effect of waterlogging was to restrict the roots to the upper layers during the first few months of growth and to change the general character of the root system. The results are shown in Fig. 1. On the left is represented the root

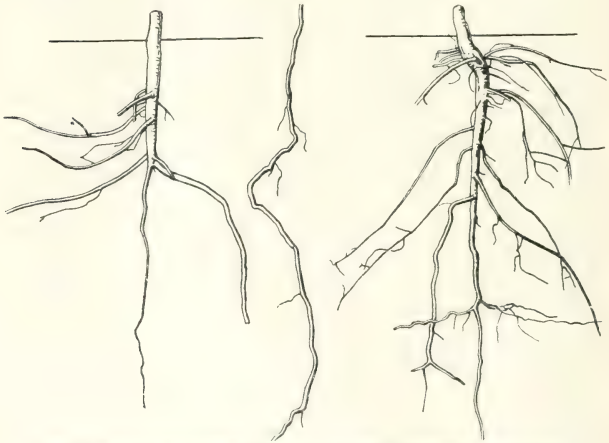


FIG. 1 The root system of Java indigo showing the effect of waterlogging before sowing (left) compared with the control (right).

system of a plant from the plot waterlogged a month before sowing, on the right a specimen of the roots from the control plot is to be seen. In the waterlogged plot, the development of the tap-root is arrested and one of the laterals after bending takes its place. In the case illustrated, the acting tap-root was followed to some distance and was found to give off very few branches.

When the subsoil is gradually waterlogged from below after the seed is sown, still greater changes in the root system are obtained. Gradual waterlogging from below after sowing is obtained by growing the crop in lysimeters, the drainage openings of which can be closed at will. In 1918, a series of such experiments was carried out and at the end the growth and root-development obtained under drained and waterlogged conditions was compared. The results are shown in Fig. 2.

FIG. 2. The effect of waterlogging after sowing on the root-development of Java indigo.

Manuring.

Although indigo is a leguminous plant there is a copious development of nodules only after the early rains, so that it responds markedly to nitrogen applied in the form of organic matter such as leaf-mould, farmyard manure or oilcake. That nitrogen is required by the young crop is suggested by the waterlogging experiment carried out in September 1917, which is described above. This indication has been confirmed by the results of numerous field experiments and of several series of pot cultures. The chief effect of the organic matter is to stimulate the seedlings and to help the crop to establish itself. If the soil is too poor at sowing time, numerous bare patches in the field develop and the crop looks thin and starved. Organic matter, on the other hand, leads to dark foliage and to strong growth. The effects persist till the break of the rains when they pass off due, in all probability, to the result of the intense nodular development which is such a feature of the crop at this period. Even during the rains, the indigo crop appears to make use of combined nitrogen as the cereal crops like wheat and oats which follow indigo compared with those on fallow land never show any great vegetative vigour and exhibit all the signs of a reduced supply of available nitrogen.

The effect of available phosphate on growth has been investigated by growing indigo in two sets of lysimeters—one filled with alluvial soil from Kalianpur and the other with Pusa soil. Kalianpur soil is exceedingly rich in available phosphate (0·318 per cent) while Pusa soil, when analysed by Dyer's method, gives very low figures (0·001 per cent) for available phosphate. In spite of this the growth has always been greater in Pusa soil than in Kalianpur soil as the following measurements taken on September 11th, 1918, show :—

	Average height of plants in inches.
Pusa soil	10·7
Kalianpur soil	5·0

A second similar set of measurements were made on September 15th, 1919, with the following results :—

	Average height of plants in inches.
Pusa soil	36·4
Kalianpur soil	20·1

These figures afford no support to the view that manuring with superphosphate will increase the growth of Java indigo.

PUSA :
20*th November*, 1919.

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